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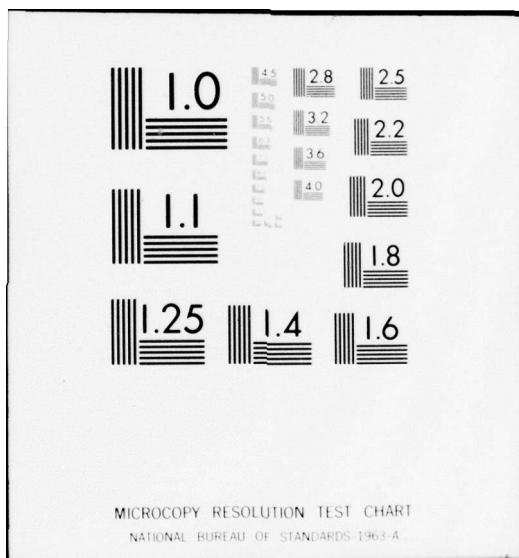
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### Physical Constraints on Waterway Use

Peter R. Ingold

15 November 1973

Technical Report No. 3

Department of Geography  
University of Michigan

Research Project Nonr 1224(56)  
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## PREFACE

This report is one of a series of publications concerned with development topics in Southeast Asia. The research detailed in this report represents a portion of a larger study sponsored by the Applied Scientific Research Corporation of Thailand which dealt with an analysis of transportation systems in Thailand. This study, designated as Research Project 30, was the joint undertaking of the University of Michigan and the Applied Scientific Research Corporation of Thailand and was funded by the University from a research contract with the Geography Branch of the Office of Naval Research (Research Project Nonr 1224 (56) N.R. No. 388080). Research and analysis was conducted by both Corporation and University personnel under the direction of Professor L. A. Peter Gosling, Department of Geography, University of Michigan.

Co-ordination of the project publications and editorial assistance were provided by Catherine J. Baker. Inquiries regarding the publication series should be directed to the Department of Geography, University of Michigan, Ann Arbor, Michigan, U.S.A. The conclusions, opinions and recommendations of the various authors in these reports do not necessarily reflect the views of any of the sponsoring organizations.

This report, Physical Constraints on Waterway Use, was originally part of a dissertation offered for the degree of Ph.D. in Geography by Peter R. Ingold. Field work was conducted in Thailand as a part of

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potential level of barge transport efficiency is described for the three major routes of the middle Chao Phaya system, the Noi, the Suphan and the Chao Phaya.



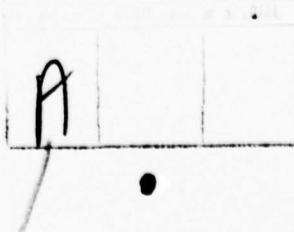
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Physical constraints on waterway use pose the major problem in increasing the efficiency of the water transport system. Seasonal variation in water levels due to seasonal rainfall provides the major limitation on efficient use of the main river channels. The presence of sand-bars and shallows, the problems of high velocity riverine and tidal currents, and the high sinuosity index of some channels all contribute to increase the hazard, cost and travel time of water transport. Development programs for water transportation will find these physical problems the most difficult and costly to solve.

L. A. P. Cosling  
Project Director



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## PHYSICAL CONSTRAINTS ON WATERWAY USE

### Introduction

This report sets as its task an examination of some of the major constraints faced by water transportation, particularly those that increase barge travel times. Major focus will be placed upon the middle region's waterways, the Suphan, Noi and Chao Phaya rivers. The actual time it takes a loaded barge to make the journey through the middle Chao Phaya river region to the Bangkok area depends on a number of physical and economic constraints, as well as the barge operator's ability to counteract such restraints. These physical constraints or hazards include such variables as depth of channel, configuration of channel, water currents and size of navigation locks and resulting traffic congestion. Additional economic and organizational problems include such things as poor security and inadequate market information.

When faced with one or a combination of these physical constraints and related increases in travel time, the barge operator has a range of options which he can exercise. They will, to some extent, work to minimize the hazards faced, cut travel times, reduce operating expenses or some combination of these factors. In response to physical hazards there are options as, the size of the barge used, the

amount of cargo hauled, the horsepower of the towboat selected, the length of the barge tow joined, the position on the tow, and the channel selected. In response to the non-physical hazards there are such options as, theft insurance, the interdependence and mutual support of kinship groupings and travel associations, and an operator's own personal experience.

#### Depth of Channel: Variations in River Flow and Level

The main reason that water transport is unable to operate throughout the year in all parts of the Chao Phaya system is the seasonal variations that occur in river flow and the related variations that occur in channel depths. This situation is reflective of the annual rainfall pattern and the gentle gradient of the Central Plain.

#### Seasonal Rainfall

The motive force behind Thailand's rainfall pattern is the seasonal reversal of wind direction associated with the monsoon climatic regime and common to most of the Southeast Asian realm. The actual time of wind shift and the nature of its impact on the landscape is in large measure a function of location in relation to the Asian landmass to the north and the warm equatorial seas to the south. Within the Central Valley of Thailand, two factors govern the quantity of precipitation received: relief and distance from the sea. Along the western flank of the Central Valley, the orographic influence of the Central Cordillera creates a rain shadow that sharply reduces total rainfall along its eastern or leeward side. Kanchanaburi and Tak, both situated in this

dry zone, receive reduced amounts of rain. The annual average rainfall at Kanchanaburi is 46.55 inches (1,182.36 mm.) while farther north in Tak it falls to 40.66 inches (1,032.90 mm.).<sup>1</sup> To the east of Bangkok, the slope of the Khorat plateau forces oncoming air masses to rise along its flank. Precipitation stations located along this escarpment receive heavy rainfalls. Nakhon Nayok, critically situated in the path of the rising masses of air, records an annual average of 80 inches (2,032.00 mm.) of rain.<sup>2</sup> The top of the plateau to the east suffers from being in a rain shadow. Nakhon Ratchasima reports an annual average of only 45.48 inches (1,155.20 mm.).<sup>3</sup>

In a northerly direction, precipitation decreases in proportion to each station's distance from the sea. Moving up the Central Valley, Bangkok receives an average annual total of 60.24 inches (1,530.00 mm.), Lop Buri 54.25 inches (1,378.00 mm.), and Nakhon Sawan 46.91 inches (1,191.10 mm.).<sup>4</sup> Beyond Nakhon Sawan in the upper valley, annual average monthly rainfall rates once again begin to increase as the rise in elevation promotes orographic precipitation. Moving northward, Phitsanulok records an average of 53.17 inches (1,350.50 mm.) of rain, and Uttaradit, in the northernmost reaches of the upper valley, records 55.23 inches (1,402.80 mm.) of rainfall per year.<sup>5</sup>

In Thailand, four seasons are commonly recognized. Two of these seasons are easily identified by the extremes they display, the wet or rainy season and the dry season.<sup>6</sup> The rainy season, also known as the summer or southwestern monsoon, is dominant from May to October. It is characterized by warm, moist winds that blow from the sea out of the south-western quadrant.<sup>7</sup> During this season, continental Thailand

receives the bulk of its annual precipitation. Temperatures are moderately high while the sky is overcast much of the time. The dry season, also known as the winter or northeast monsoon, is the time of year that the prevailing winds blow from the interior out of the north-eastern quadrant. During the months of December through February, temperatures reach their lowest point, the sky is clear and precipitation is practically nil throughout the kingdom (see Figure 1 and Table 1).<sup>8</sup>

The remaining two of Thailand's four seasons are transitional in nature and are more difficult to identify. The period of the retreating monsoon occurs October through November. At this time of year, the prevailing wind undergoes a shift in direction from one blowing predominantly out of the southwest, or onto the continent, to one blowing out of the northeast or out of the interior of the landmass.<sup>9</sup> As the wind executes this south to north migration, the climatic regime experienced in Thailand shifts from the wet or rainy season to the dry or winter season.

The transitional hot season occurs in March, April, and May. At this time of year, the dominant control continues to be the continental high pressure system to the north. Locally, high temperatures cause an increased variability in wind direction. Occasionally, cyclonic precipitation activity may be produced as a result of the collision of cool, northerly air with warmer air from the south.<sup>10</sup> Generally, as is shown by Figure 1 and Table 2, at this time of year, high temperatures and low amounts of precipitation combine to create conditions of near aridity.

## BANGKOK

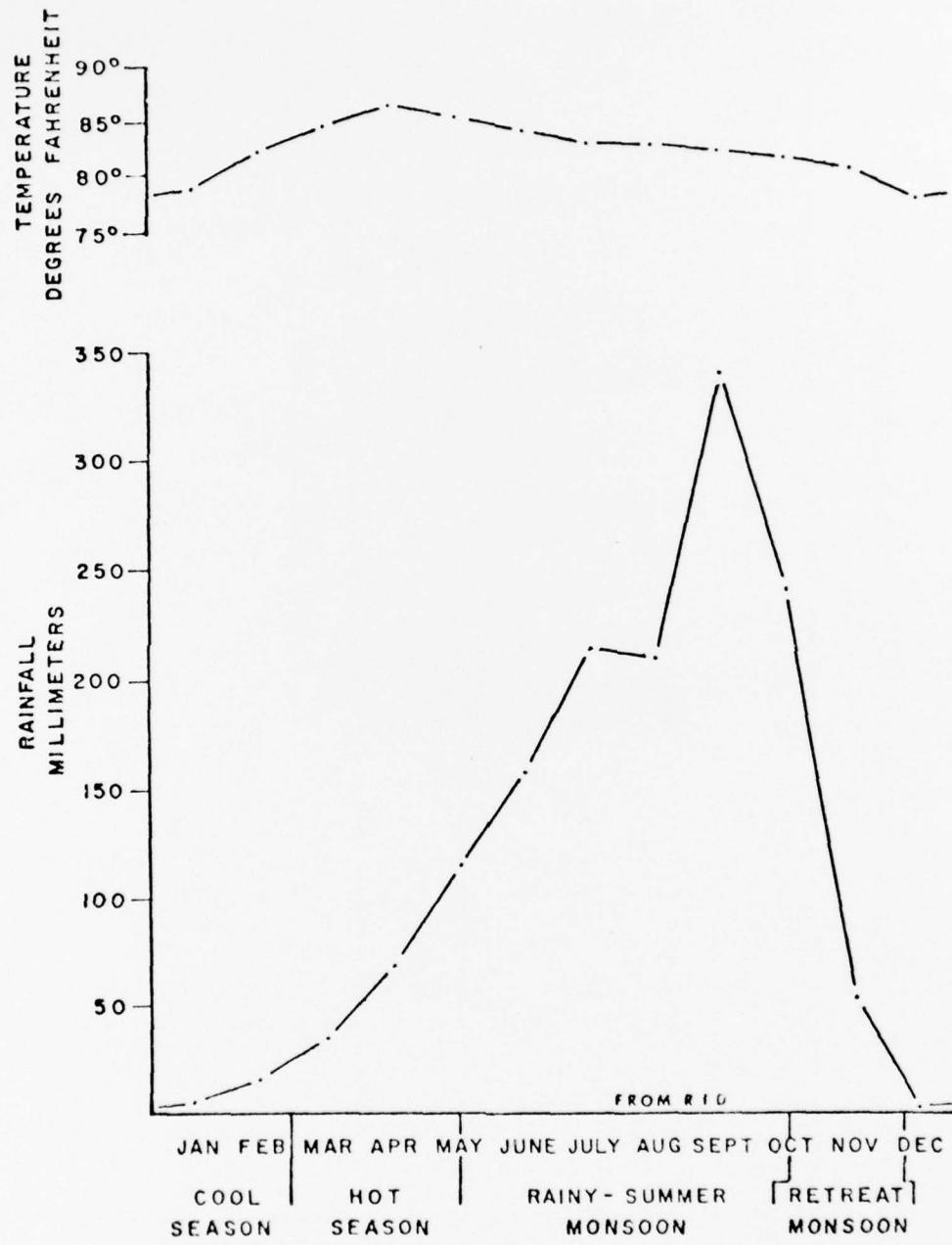


Figure 1. Climatic information relating to Bangkok as recorded by the Royal Irrigation Department. Twenty-one year average, 1937-1958.

TABLE 1  
MONTHLY MEAN PRECIPITATION RECEIVED AT SELECTED STATIONS IN THAILAND'S CENTRAL REGION  
(IN MILLIMETERS)

Station	January	February	March	April	May	June	July
Bangkok	8.86	17.69	33.84	69.93	144.60	158.90	216.37
Lop Buri	22.26	16.04	92.52	66.04	149.20	154.12	182.30
Kanchanaburi	3.22	19.62	33.39	62.32	138.88	99.31	126.55
Suphan Buri	2.40	11.00	60.09	52.87	157.47	122.43	138.80
Nakhon Sawan	10.17	36.80	50.81	70.33	151.67	117.93	152.72
Phitsanulok	7.98	14.62	52.83	48.99	194.32	167.71	189.90
Uttaradit	11.86	22.65	32.41	75.86	174.71	199.82	219.39
Chiang Mai	16.59	12.42	22.78	53.63	179.60	289.04	188.90

Station	August	September	October	November	December	Total	Yearly
Bangkok	212.36	343.99	270.02	55.66	1.88	1,530.07	
Lop Buri	159.73	294.48	215.52	45.49	0.23	1,377.93	
Kanchanaburi	105.58	255.93	274.86	60.80	1.87	1,182.36	
Suphan Buri	172.70	303.81	285.17	59.78	0.60	1,363.53	
Nakhon Sawan	159.18	276.89	142.34	21.31	1.58	1,191.64	
Phitsanulok	203.90	263.13	121.76	22.74	2.15	1,350.49	
Uttaradit	233.89	289.88	107.84	19.98	4.67	1,402.94	
Chiang Mai	215.02	253.98	133.07	28.53	11.05	1,524.21	

Calculated from: Thailand, Ministry of Agriculture, Royal Irrigation Department, Hydrology Section (unpublished records, Bangkok).

TABLE 2  
MONTHLY MEAN TEMPERATURES AT SELECTED STATIONS IN THE CENTRAL VALLEY IN DEGREES F.

Station	Years	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Bangkok	1937- 1958	78.98	82.22	84.74	86.54	85.46	84.02	83.30	83.12	82.58	81.86	80.42	77.70
Kanchan- aburi	1949- 1958	77.40	82.22	86.72	87.98	86.72	84.38	83.48	82.94	82.58	80.96	78.26	75.20
Lop Buri	1943- 1958	78.98	83.30	86.36	86.72	85.82	83.84	82.94	82.58	82.22	81.50	79.34	77.18
Nakhon Sawan	1939- 1958	77.36	81.86	86.54	87.98	86.72	85.28	84.56	83.84	83.12	82.58	79.88	76.10
Phitsa- nulok	1937- 1958	75.92	80.06	84.56	86.90	86.00	84.20	83.48	83.12	83.12	82.58	80.24	75.92
Uttara- dit	1940- 1958	75.38	79.52	84.56	87.67	86.40	84.20	83.48	82.94	83.66	82.76	80.06	75.74
Chiang Mai	1937- 1958	70.34	73.58	78.08	82.94	83.48	82.22	81.32	80.60	80.49	79.16	76.10	70.88

Calculated from: Thailand, Ministry of Agriculture, Royal Irrigation Department, Hydrology  
Section (unpublished records, Bangkok).

### Rainfall Variability

As one would suspect of all meteorological phenomena, the generalized outline of the ebb and flow of monsoonal air currents presented above often undergoes dislocation. Precipitation variability from station to station is common throughout the kingdom. Generally, an inverse relationship exists between the annual total amount of rainfall a station receives and the predictability of its abundance in any one month from year to year.<sup>11</sup> Table 3, based on Lawrence Sternstein's The Rainfall of Thailand, presents the minimum, maximum relative variations in rainfall recorded at selected stations in the Central Valley.

As Table 3 indicates, variability is the greatest during the winter months; lowest during the summer monsoon. The summer months, however, are not without their problems in regards to precipitation variability. In some years the arrival of the rains in May or early June is decisive and on schedule, yet in other years its coming is gradual and late. Just how wide these aberrations are from year to year is impossible to predict in advance.

Tables 4 and 5 present data on monthly precipitation receipts and summer dry spells at two stations on the Central Plain. The months for which data are presented in these tables have been limited to those normally dominated by the summer monsoon. As the data illustrate, in addition to arriving late, the summer monsoon can occasionally terminate earlier than is normally expected.

Still another variable factor is the monsoon's capacity for occasionally pausing midway through the rainy season for varying lengths

TABLE 3

MINIMUM, MAXIMUM AND ANNUAL RELATIVE RAINFALL VARIATIONS  
 FOR SELECTED STATIONS IN THE CENTRAL PLAIN  
 1951-1960

	Annual Variation %	Minimum Variation		Maximum Variation	
		Month	%	Month	%
Chaing Mai	13.8	Aug.	13.7	Dec.	139.1
Lampang	12.3	Sept.	23.1	Jan.	136.9
Uttaradit	10.3	Sept.	20.1	Dec.	178.7
Pitsanulok	8.7	Sept.	17.2	Dec.	154.5
Nakhon Sawan	16.3	Sept.	13.1	Feb.	131.5
Suphan Buri	8.6	July	23.9	Jan.	145.8
Lop Buri	14.7	July	25.2	Dec.	150.0
Bangkok	16.3	Sept.	13.1	Feb.	131.5

Source: Based on Lawrence Sternstein, The Rainfall of Thailand,  
 edited by Don C. Bennett (Bloomington, Indiana: Indiana  
 University Foundation Research Division, n.d.).

TABLE 4

PRECIPITATION VARIABILITY FOR MONTHS OF THE SUMMER MONSOON  
AT TWO STATIONS ON THE CENTRAL PLAIN<sup>c</sup>

Year	Bangkok					
	May		+ or - from Mean <sup>b</sup>	June		+ or - from Mean
	Days <sup>a</sup>	mm. rec.		Days	mm. rec.	
1947	10	112.8	- 45.2	15	45.6	-103.7
1948	23	276.3	+118.3	15	106.7	+ 11.4
1949	16	226.5	+ 68.5	13	124.4	- 24.9
1950	18	151.4	- 6.6	20	171.0	+ 21.7
1951	12	205.2	+ 47.2	18	206.8	+ 57.5
1952	13	125.9	- 32.1	20	128.7	- 20.6
1953	19	213.8	+ 55.8	17	144.2	- 5.1
1954	12	169.2	+ 11.2	17	199.8	+ 20.5
1955	20	207.2	+ 49.2	14	102.6	- 46.7
1956	20	121.0	- 37.0	19	169.4	+ 20.1
1957	8	36.9	-121.9	17	244.3	+ 95.0
1958	10	36.9	-121.1	16	175.3	+ 26.0
1959	14	218.7	+ 60.7	11	138.5	- 10.8
1960	13	112.0	- 46.0	13	79.4	- 69.9

Mean = 158.0

Mean = 149.3

 $\bar{T} = 70.95$  $\bar{T} = 48.87$

TABLE 4 --(continued)

Year	Bangkok					
	July			August		
	Days <sup>a</sup>	mm. rec.	+ or - from Mean <sup>b</sup>	Days	mm. rec.	+ or - from Mean
1947	16	147.7	- 64.3	20	131.5	- 7.4
1948	22	210.8	- 1.2	19	116.8	- 38.7
1949	21	336.7	+124.7	28	259.7	+ 54.2
1950	18	135.6	- 76.4	18	195.6	- 9.9
1951	21	229.4	+ 17.4	12	186.0	- 19.5
1952	18	179.0	- 33.0	25	223.7	+ 17.6
1953	18	365.6	+153.6	20	158.0	- 47.5
1954	24	314.2	+102.2	24	206.7	+ 1.2
1955	15	244.6	+ 32.6	21	189.9	- 15.6
1956	16	103.3	-108.7	23	193.9	- 11.9
1957	16	165.0	- 47.0	25	302.6	+ 97.1
1958	20	168.0	- 44.0	22	317.0	+111.5
1959	23	240.2	+ 28.2	18	102.5	-103.0
1960	16	127.4	- 84.6	21	243.9	+ 38.4

Mean = 212.0  
 $\bar{r} = 78.38$

Mean = 205.5  
 $\bar{r} = 58.12$

	September			October		
	Days	mm. rec.	+ or - from Mean	Days	mm. rec.	+ or - from Mean
1947	21	276.7	- 41.6	14	147.8	-119.1
1948	18	237.2	- 81.1	17	331.9	+ 65.0
1949	18	213.3	-105.0	18	253.4	- 13.5
1950	21	289.3	- 29.0	22	303.0	+ 36.1
1951	22	239.8	+ 78.5	16	338.2	+ 71.3
1952	22	298.3	- 20.0	26	403.4	+136.5
1953	21	316.3	- 2.0	17	113.6	-153.3
1954	24	295.6	- 22.7	14	107.2	-159.7
1955	19	487.3	+169.0	15	164.8	-102.1
1956	25	365.2	+ 46.9	12	189.1	- 77.8
1957	25	448.4	+130.1	18	490.1	+223.2
1958	20	278.7	- 39.6	20	228.7	- 38.2
1959	21	210.3	-108.0	19	224.6	- 42.3
1960	26	499.7	+181.4	17	440.5	+173.6

Mean = 318.3  
 $\bar{r} = 93.00$

Mean = 266.9  
 $\bar{r} = 117.18$

TABLE 4 --(continued)

Year	Nakhon Sawan					
	May		June			
	Days <sup>a</sup>	mm. rec.	+ or - from Mean <sup>b</sup>	Days	mm. rec.	+ or - from Mean
1948	18	116.5	- 38.0	12	90.6	- 31.4
1949	11	83.7	- 70.8	11	91.8	- 30.2
1950	20	292.7	+138.2	20	224.9	+102.9
1951	12	260.6	+106.1	15	59.5	- 62.5
1952	15	217.7	+ 63.2	11	181.7	+ 59.7
1953	11	82.3	- 72.2	16	66.4	- 55.6
1954	14	208.7	- 54.2	13	112.1	- 9.9
1955	12	284.3	+129.8	12	144.4	+ 22.4
1956	15	172.9	+ 18.4	17	179.1	+ 57.1
1957	5	69.1	- 85.4	13	138.6	+ 16.6
1958	6	46.6	-107.9	13	91.4	- 30.6
1959	12	110.1	- 44.4	11	51.7	- 70.3
1960	11	64.0	- 90.5	11	154.4	+ 32.4

Mean = 154.5

T = 85.59

Mean = 122.0

T = 58.06

	July			August		
	Days	mm. rec.	+ or - from Mean	Days	mm. rec.	+ or - from Mean
1948	18	197.7	+ 49.7	19	162.0	+ 9.3
1949	17	142.2	- 5.8	XX	XX	XX
1950	17	57.9	- 90.1	16	79.1	- 73.6
1951	17	211.8	+ 63.8	15	134.4	- 18.3
1952	12	90.0	- 58.0	18	114.0	- 38.7
1953	18	185.9	+ 37.9	19	183.8	+ 31.1
1954	10	51.2	- 96.8	20	189.7	+ 37.0
1955	21	244.2	+ 96.2	16	180.3	+ 27.6
1956	18	195.2	+ 47.2	15	128.5	- 24.2
1957	13	73.1	- 74.9	21	209.2	+ 56.5
1958	11	95.0	- 53.0	12	145.9	- 6.8
1959	18	217.4	+ 69.4	11	184.1	+ 31.4
1960	13	163.4	+ 15.4	14	121.9	- 30.8

Mean = 148.0

T = 64.34

Mean = 152.7

T = 40.66

TABLE 4 --(continued)

Year	September			October		
	Days <sup>a</sup>	mm. rec.	+ or - from mean <sup>b</sup>	Days	mm. rec.	+ or - from Mean
1948	22	238.8	- 21.6	17	205.2	+ 94.1
1949	17	189.4	- 71.0	12	135.5	- 20.6
1950	17	187.8	- 72.6	18	220.3	+ 64.2
1951	15	271.0	+ 10.6	15	319.1	+163.0
1952	17	254.6	- 14.8	16	375.8	+219.7
1953	16	362.4	+102.0	12	160.0	+ 3.9
1954	23	332.1	+ 71.7	7	29.6	-126.5
1955	15	264.4	+ 4.0	6	28.9	-127.2
1956	19	250.4	- 10.0	11	168.5	+ 12.4
1957	18	276.4	+ 16.0	8	135.0	-177.8
1958	20	294.2	+ 33.8	4	43.2	-112.9
1959	19	299.8	+ 39.4	9	19.8	-136.3
1960	12	172.6	- 87.8	14	143.5	- 12.6

Mean = 260.4
Mean = 156.1

$\bar{V} = 23.83$ 
 $\bar{V} = 119.17$

<sup>a</sup>Rainy days defined as a 24 hour period beginning at 7 AM and during which time at least 1/10 of a mm. of rain has fallen.

<sup>b</sup>Deviation from mean in mm.

Source: Lawrence Sternstein, The Rainfall of Thailand.

TABLE 5

DRY SPELLS FROM MAY TO SEPTEMBER 1951 TO 1960<sup>a</sup>

Station	Ave. No./Yr.	Ave. No. Days/Yr.	Three Longest Days/ Mo.	Least No.	Most No.
Bangkok	8	4	June	14	5
			May	12	
			May, May/June	8	
Nakhon Sawan	11	5	May/June	14	8
			May	13	
			May(2)	12	

<sup>a</sup>A dry spell is here defined as a period of three or more consecutive rainless days. A rainless day is one having less than 0.1 mm. (0.004 inches) of rain on record.

Source: Lawrence Sternstein, The Rainfall of Thailand.

of time. These breaks in the summer monsoon's rain bringing activities usually occur in August.<sup>12</sup>

Regardless of the causes behind these phenomena, any significant deviation from the norm has a negative impact on both agriculture and inland navigation. Especially in the early weeks of the summer monsoon, aberrations in the precipitation pattern are quickly felt in terms of the amount of water available to irrigate the nation's young rice crop or to fill its navigation channels. In the early summer months, water tables are low after the long dry season. Recharging this water deficit especially in the higher portions of the watershed takes time and absorbs water that, later in the rainy season, flows to the region's streams and rivers.<sup>13</sup> Figure 2 shows water levels over a six year period at Wat Pho Ngam on the Chao Phaya river below the dam near Chai Nat. The depth of water can drop in the early months of the monsoon (May, June, and July) often after an initial crest. Later in the rainy season (August, September, and October), wide yearly variations in river level also occur, but at this time the low points are still high enough from the river bottom so as not to cause navigational problems. See additional hydrographic data presented in this chapter.

In summary, the great variation in precipitation over space and especially time accounts for the wide fluctuation in water levels in Thailand's canals and streams. Even though the monsoonal climate regime assures that most of Thailand's rain will come in the summer as opposed to any other time of year and also that relative variability will be lowest in the summer, the week or even the month in which the rains will begin or halt remains uncertain. Similarly unknown is the total amount

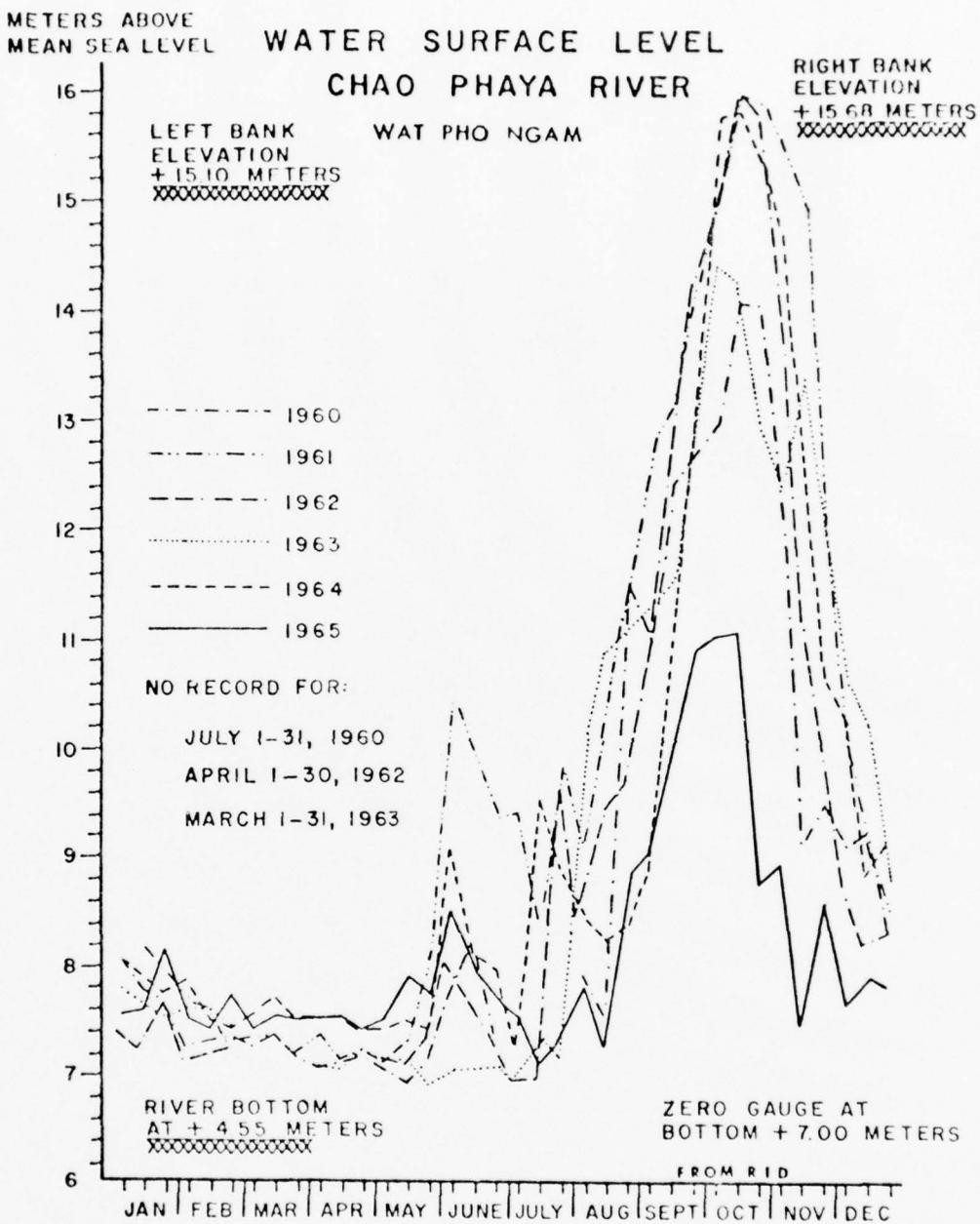


Figure 2. Hydrograph showing water surface variability at Wat Pho Ngam, a station on the Chao Phaya River located below the Chao Phaya Dam.

of rainfall that any single summer month will deliver even after the rains have begun. It is this unpredictable quality in the rainfall regime that explains the high degree of fluctuation in stream flow.

Variation in Flow and Stage

Two important components of stream condition are water flow and stage. Flow, a term often used interchangeably with discharge, is a measure of the amount of water that passes through an area within a predetermined unit of time.<sup>14</sup> It is usually stated in terms of cubic units of flow per second. To arrive at a measure of this variability, the standard practice is to lower a velocity measuring device at 25 to 30 places across a moving stream. The device measures the speed of water movement.<sup>15</sup> In Thailand this measure is usually expressed in terms of so many cubic meters of water per second, or, in a simpler fashion, as  $m^3/sec.$  Each of the 25 to 30 observations taken is then summed and a mean velocity is computed.<sup>16</sup> This figure in turn is multiplied by the cross-sectional area of the stream at the point where gauging was carried out.<sup>17</sup> These relationships can be simply expressed in the following equation in which Q is defined as the volume of water moving through a given area during a given unit of time, V as the mean velocity and A as the cross-sectional area.<sup>18</sup>

$$Q = A \cdot V$$

The resulting average rate of flow for a 24 hour day is termed the mean daily discharge and is ordinarily employed as the measure of the daily flow of a river.<sup>19</sup>

Stage refers to the elevation of a stream's surface above some datum plain, usually mean sea level. In computing stage, water level is graphed on a continuous time line.<sup>20</sup> Along Thailand's water courses, in most cases, observations are carried out manually by scheduled readings of water level on a graduated gauging staff permanently mounted in concrete on the river bottom.

The monsoonal nature of Thailand's climatic regime with its long dry season followed by one of heavy rainfall is clearly reflected in the wide seasonal fluctuations in stage and flow experienced throughout the Chao Phaya drainage basin. The data from various river gauging stations presented in Figures 3 through 9 record a maximum flow and highest water levels in mid-September and October. In November there is a very rapid fall which lasts from four to six weeks.<sup>21</sup> Minimum flow and stage is reached in April and May.

The data presented in the ensuing illustrations are presented in two groupings. The observations presented in Figures 3 through 6 consist of monthly average river surface readings taken over several years before data were collected for this study. The second grouping, Figures 7 through 9, array readings that were taken by month during the period that Project 30 workers were gathering data, a portion of which appears in this dissertation. In both groupings, the seasonality of precipitation is clearly evident.

In September when the Central Plain's rivers reach flood stage, their currents are swift and their sediment loads are high giving the swirling waters a reddish brown color. Here and there the water's surface is dotted with debris that has been torn from some embankment

WATER SURFACE LEVEL CHAO PHAYA RIVER  
NAKHON SAWAN 1960-1965

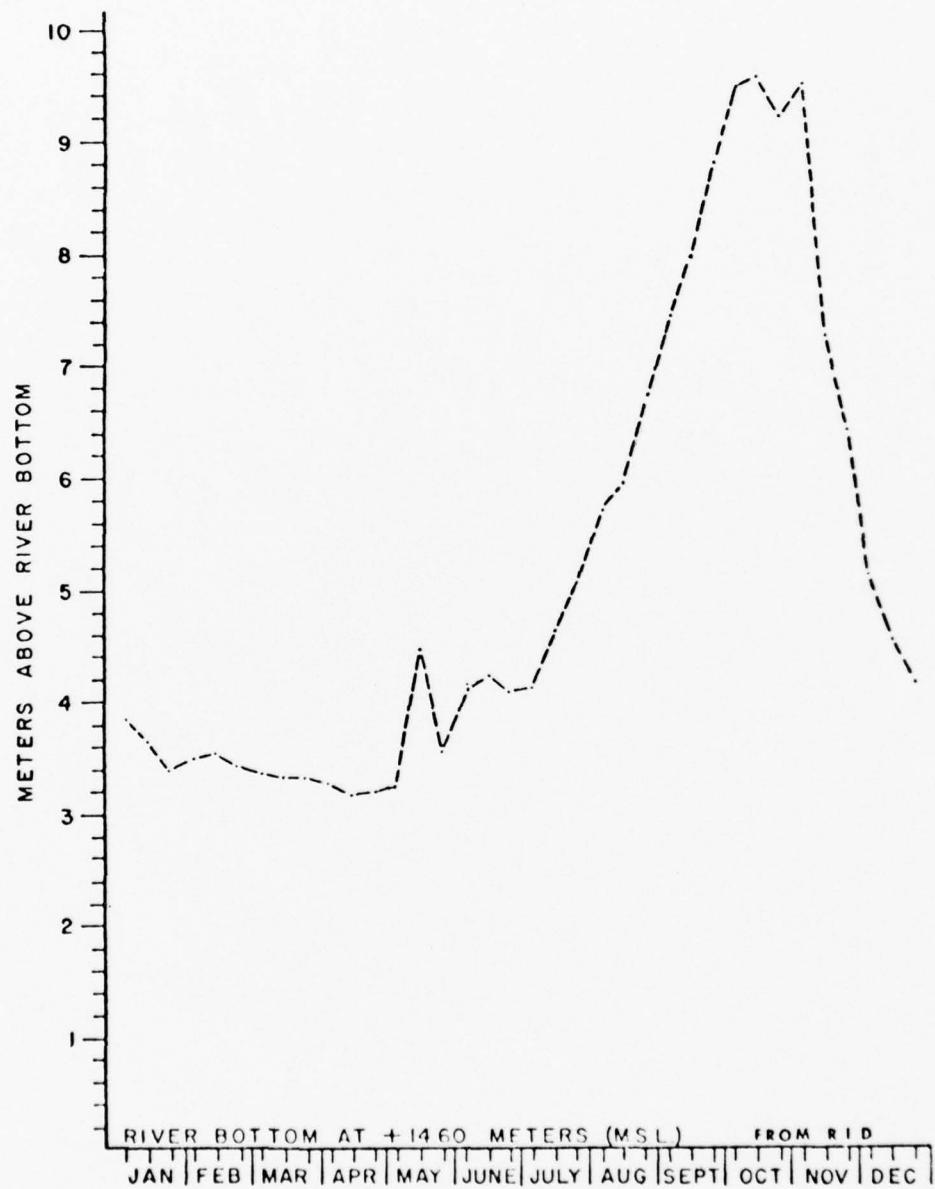


Figure 3. Maximum height hydrograph based on a five year water surface average as recorded on the 5th, 15th and 25th day of each month.

WATER SURFACE LEVEL CHAO PHAYA RIVER  
WAT PHO NGARM 1960-1965

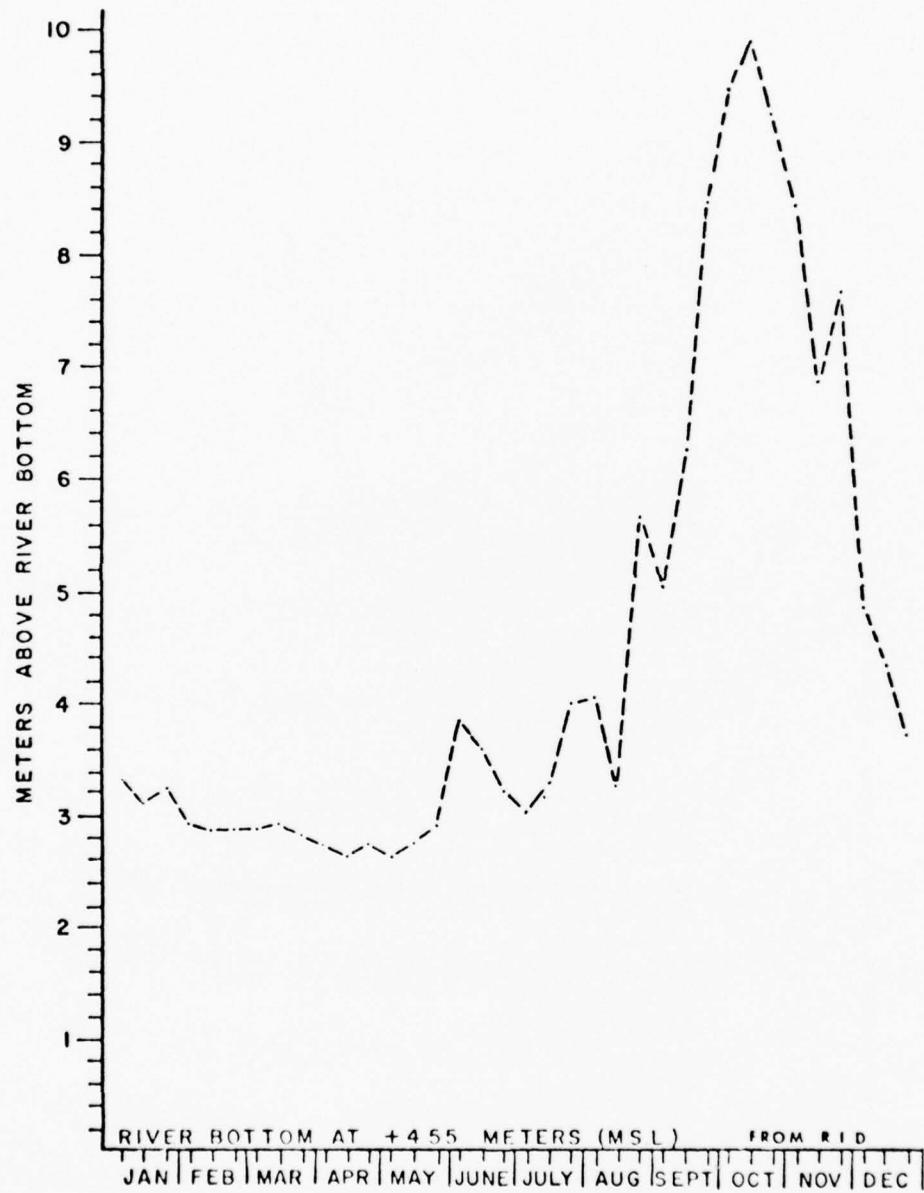


Figure 4. Maximum height hydrograph based on a five year water surface average as recorded on the 5th, 15th and 25th day of each month. This station is located below the Chao Phaya Dam.

WATER SURFACE LEVEL SUPHAN RIVER  
POLTHEP REGULATOR 1957 - 1965

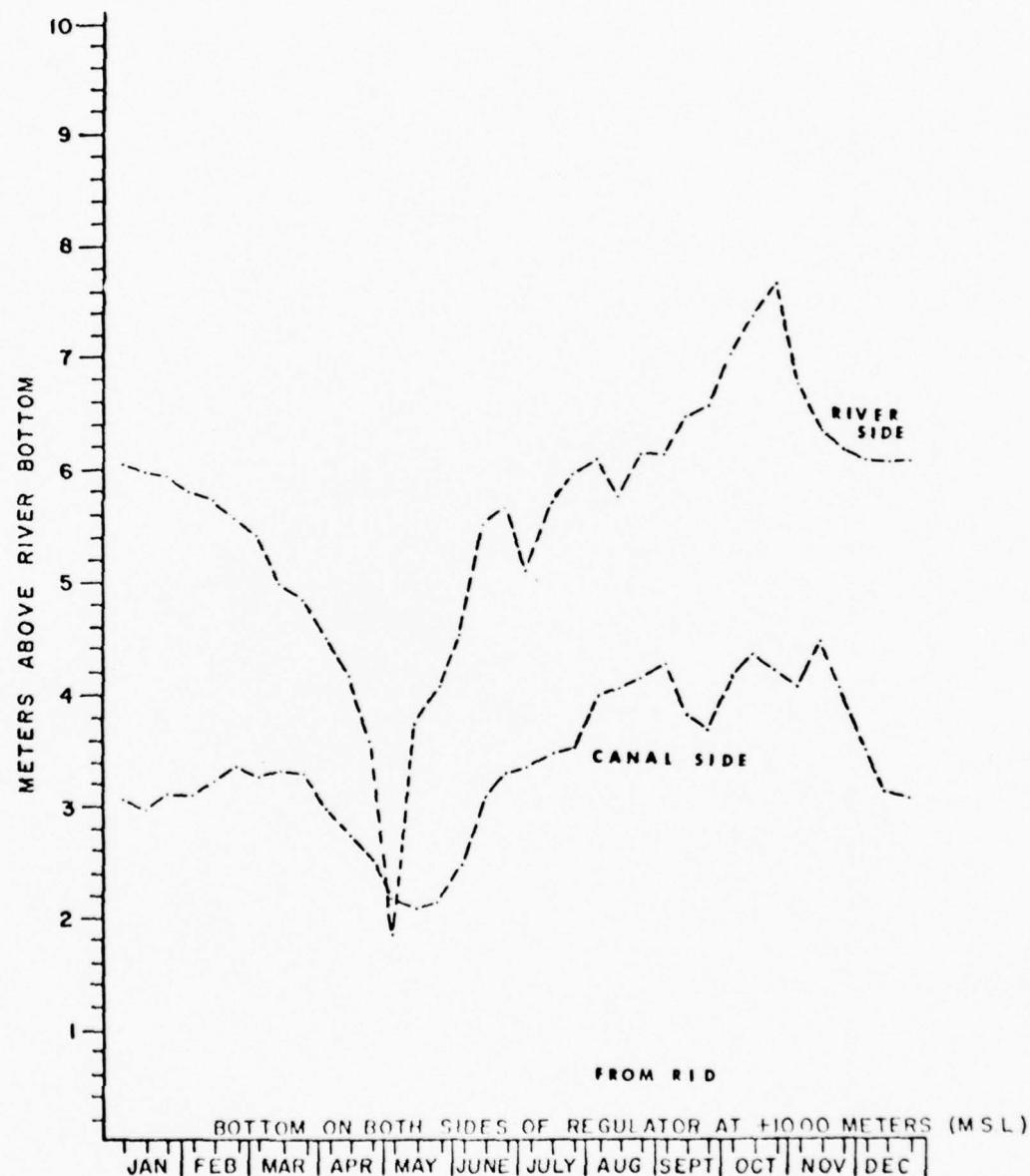


Figure 5. Maximum height hydrograph based on an eight year water surface average as recorded on the 5th, 15th and 25th day of each month. Readings given for both sides of regulator.

WATER SURFACE LEVEL SUPHAN RIVER  
 PHO PHAYA REGULATOR 1955 - 1964

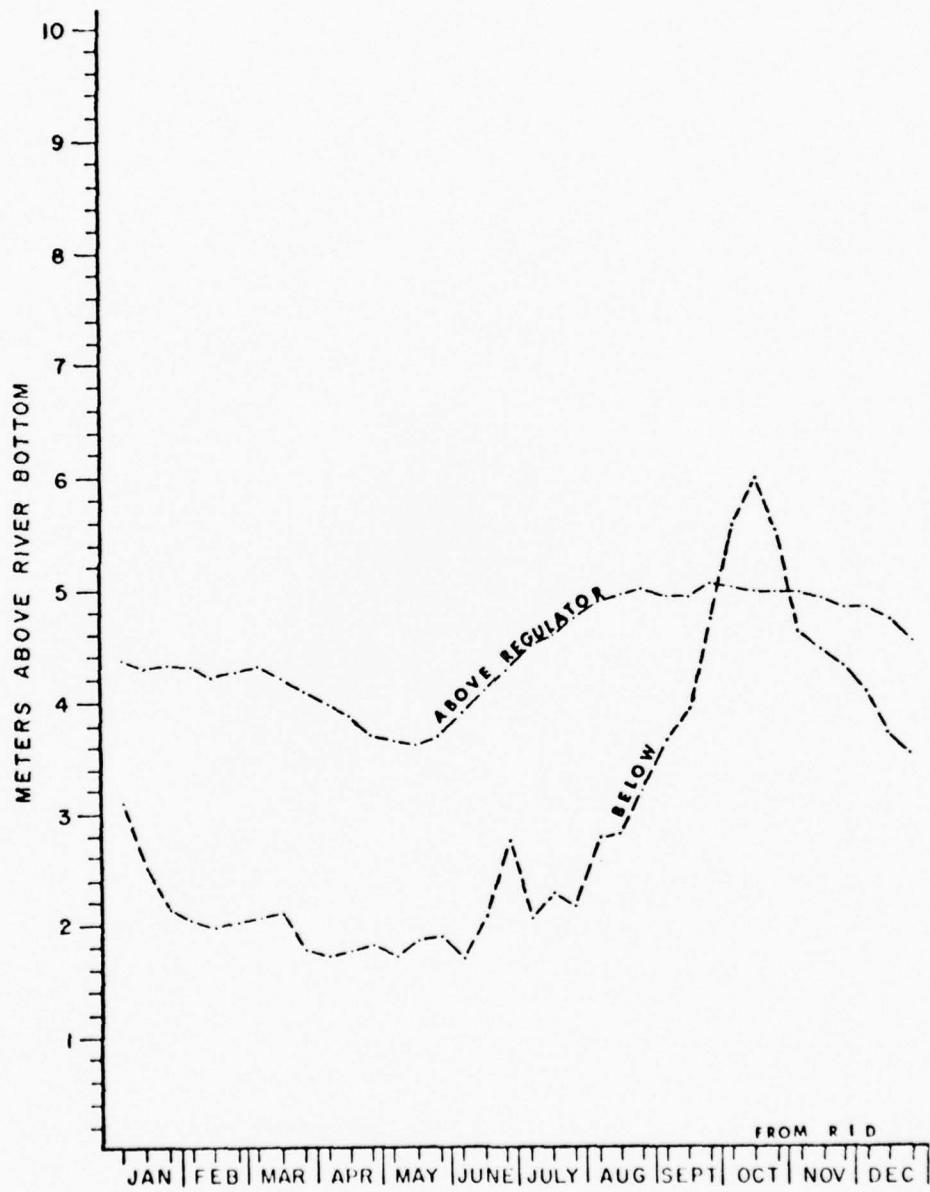


Figure 6. Maximum height hydrograph based on an eight year water surface average as recorded on the 5th, 15th and 25th day of each month. This station is in Amphoe Suphan Buri, Changwat Suphan Buri.

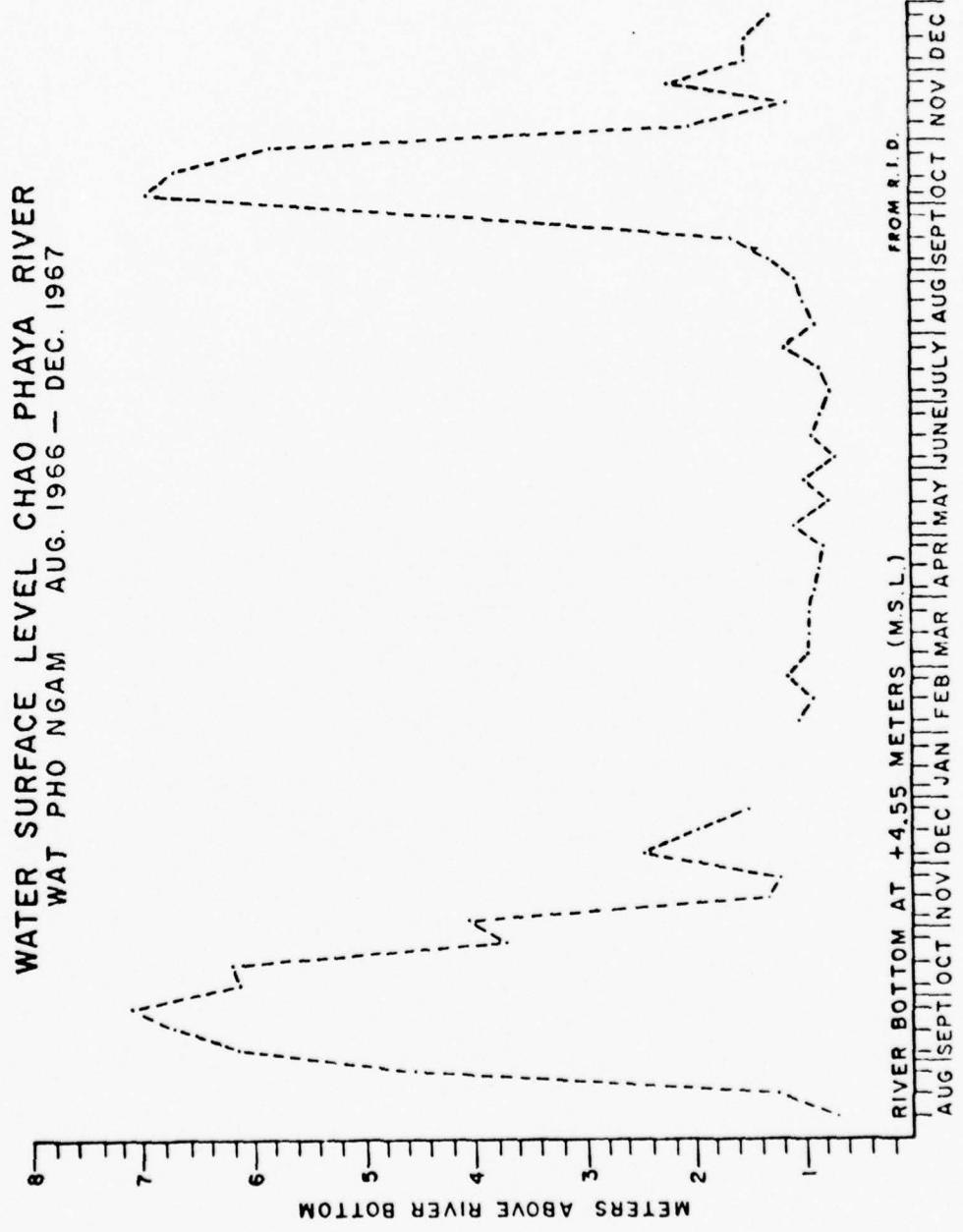


Figure 7. Maximum height hydrograph recorded on the 5th, 15th and 25th of every month during the period of Project 30's river survey. Gauging station located below the Chao Phaya Dam.

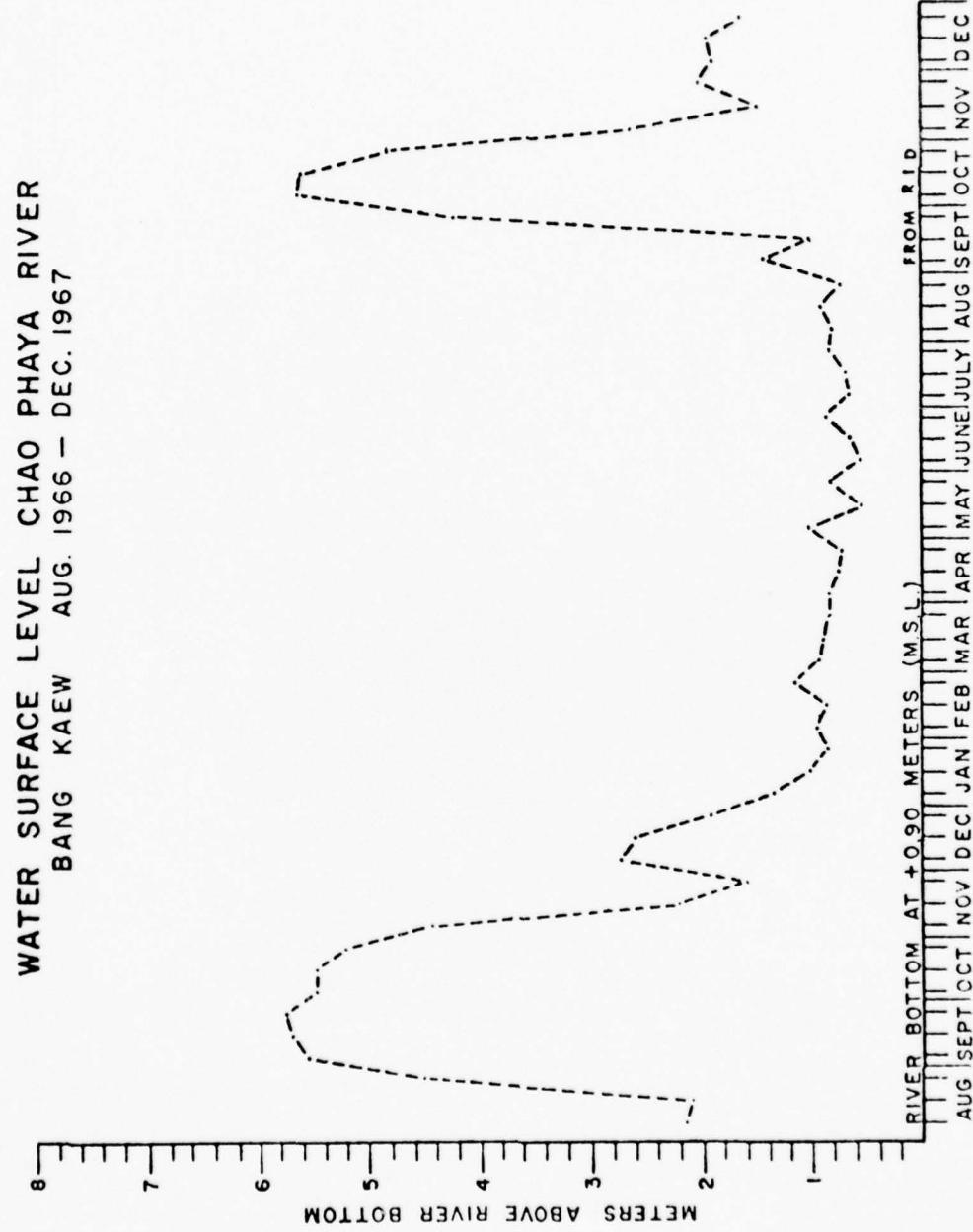


Figure 8. Maximum height hydrograph of water surface level recorded on the 5th, 15th and 25th of every month. Station located in Amphoe Ang Thong.

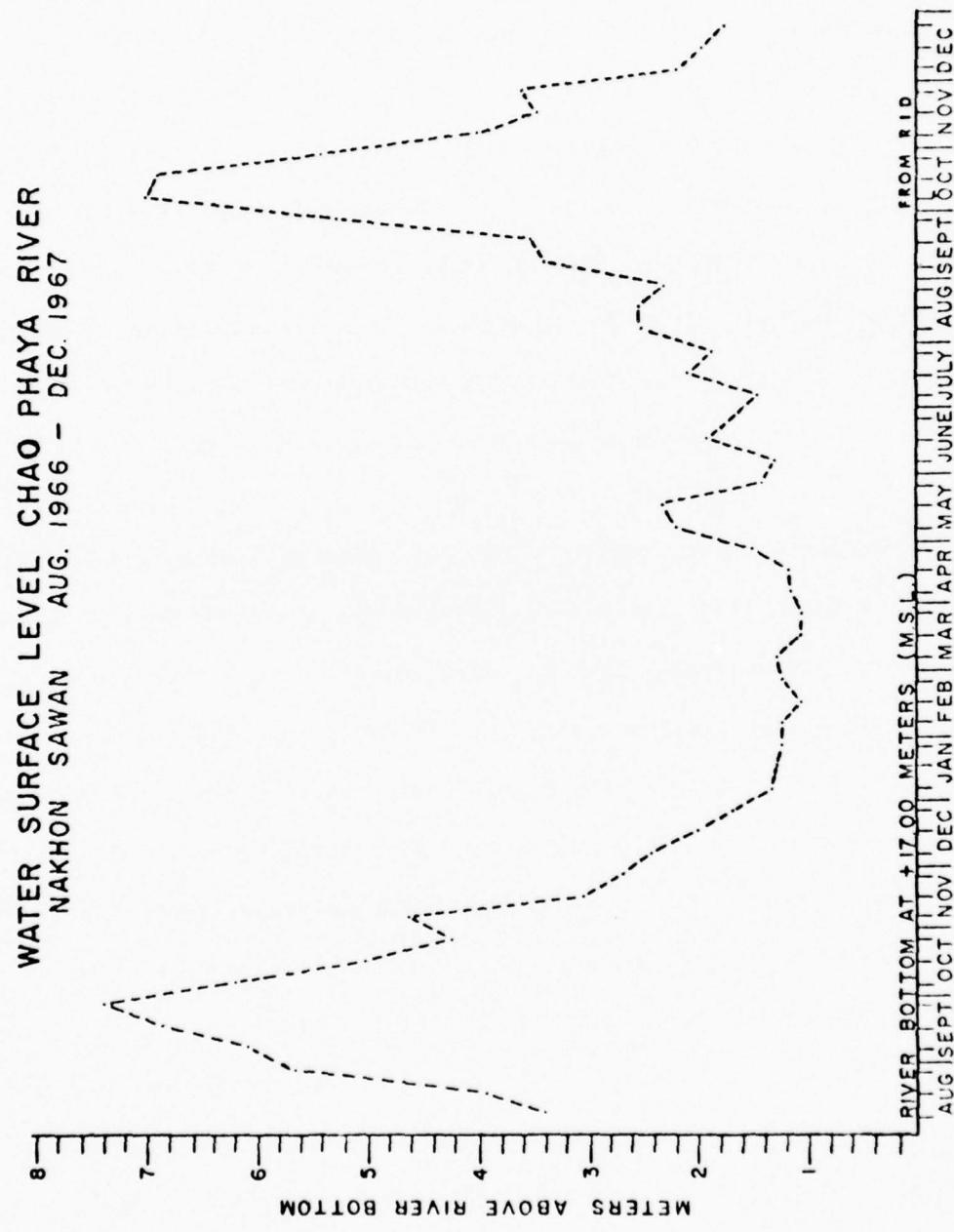


Figure 9. Maximum height hydrograph of water surface level recorded on the 5th, 15th and 25th of every month.

upstream by the rushing water. In this stage of its cycle, the river fills its entire bed to the point where its banks are often overtopped. All traces of sandbars or other shallow places disappear, having been either submerged by the high water or swept away by the stream's might. Along canals such as the Suphan and the Noi, the water levels also rise but locks and regulators control the increase and keep variation in water level at a minimum. Even on these regulated canals, current can present a problem. Along the swollen waterways of the summer monsoon, navigation is uncomplicated by obstacles caused by low water shallowness but, on the other hand, complicated by the dangers of swiftly running waters.

At the opposite extreme, i.e., the time of lowest water in April and May, quite a different view greets the eye along the Central Plain's many rivers and streams. Now the water course is much narrower as it undulates atop the river bed widening and narrowing, curving and recurving back and forth between the high-sided banks that now stand back well away from the water's edge. Owing to the decreased velocity of the flowing water, the action of sedimentation has once again caused sand bars and shoals to appear on both sides of the channel.<sup>22</sup> At this time of year the ability of the navigation channel to carry cargo vessels varies greatly from place to place between deeper pools, gravel bars and sandy shoals. Under these changeable conditions, passage by cargo craft of more than 1/2 meter draft becomes difficult or impossible. Again, it must be underlined that this description does not apply to controlled waterways like the Suphan and the Noi rivers whose levels are maintained by locks and regulators at levels required for year-round navigation.

The conditions that have been described apply to most of the rivers that flow down the Central Plain in their upper and middle reaches where the surface is of increasing elevation above mean sea level. In their lower reaches, these rivers appear somewhat different. For example, from approximately Ayutthaya southward to the sea, the Chao Phaya river does not flow between well-defined banks but spreads to either side of the observer's eye until, in the low water stage, its waters end on a slightly inclined embankment.<sup>23</sup> The extent of the bank left visible depends on the tide whose effects are felt as far upriver as Pamoke.

In flood stage when the tide is running upstream, the lower courses of the Chao Phaya expand in width to a point where the margins lie beyond the eye's reach somewhere among the water-soaked vegetation or elevated buildings that stretch along what is the river's dry season margins. At times when tidal damming is not occurring, the river's waters do end at the river bed's gently sloping banks. Thus, tidal flow, which will be discussed later in this report, can bring great changes to the river's appearance over relatively short spans of time. During the summer monsoon the entire landscape is awash and, unless one's house lies near an elevated all weather road, the principal means of rural transportation is by boat. Even the dwellings, unless raised atop man-made mounds, are built atop pilings to avoid inundation at this time of year.

Farther upstream, where the surface of the plain enjoys higher elevation above sea level, the rivers have cut their way deeper into the land's surface and, consequently, flow between the embankments described

earlier. Here also, during the rainy season, the entire landscape is well soaked but deep water is less widespread being limited to lower lying depressions placed between the natural levies which flank the water courses.<sup>24</sup>

As one would expect, a comparison of rainfall data with statistics on river flow and stage reveals a lag that, at certain times of the year, is often of several weeks duration. Numerous factors account for this lag, some natural others man-made. Among the natural explanations accounting for this lag is the condition of the drainage basin's water table. The large moisture deficit accrued during the dry season is recharged by absorption during the early weeks of the summer monsoon. Offsetting of this deficit denies large quantities of water to the region's rivers and canals. In later weeks, as the water table is recharged, surface runoff increases as does the magnitude of water in rivers and streams.<sup>25</sup> There is similar lag at the end of the summer monsoon season in November. At this time, however, the river's water levels recede more slowly than do the precipitation rates.

#### The Impact of Dams on River Flow and Depth

In addition to the variable impact of nature on the rivers and the canals of the Chao Phaya system, the works of man also have their effect. Increasingly, man has intervened in nature's regime in an effort to curb some of the more violent extremes in flow and thereby derive greater benefits from the use of the river's waters.

Two dams have been built on the waterways of the Chao Phaya system and currently a third is under construction. The oldest is the

Chao Phaya dam built across the main river directly below Chai Nat. This structure was completed in 1956. In 1966 the Yanghee or Phomiphol dam was completed on the upper Ping river. The third dam, when completed, will control the waters of the Nan river.

The main role of the Chao Phaya dam is to divert water from the main river into the extensive Greater Chao Phaya Irrigation Project. The area benefiting from this project lies in several provinces and through its network of water courses, irrigation water is delivered to 6,215,000 rais (2,460,000 acres) of what is primarily paddy land.<sup>26</sup> The project is comprised of a direct gravity irrigation system. Above the Chao Phaya dam there are distributary channels that lead water away from the main river near Chai Nat to both the east and the west. These major channels may also serve as transportation routes. On the right or west bank, water distribution is achieved by the Chai Nat-Pasak canal and, on the left or east bank, by the Noi and the Suphan rivers.<sup>27</sup> The irrigation system also contains provisions for draining low lying areas located between the main river and its distributary offshoots.<sup>28</sup>

The Chao Phaya dam and the irrigation project have diverted water from the main Chao Phaya river and have distributed it widely over the agricultural landscape. Since water for the purpose of irrigation takes precedence over water for commercial navigation, supplies that might have ordinarily flowed down the middle Chao Phaya river are now impounded for release and diversion to the irrigation system. For this reason, river levels in the middle Chao Phaya have been reduced during some months of the year when there is no rainfall but the rice crop is in need of moisture. Such a situation contributes to the passability

PING RIVER BEFORE AND AFTER CLOSURE  
OF YANGHEE DAM  
TAK GAUGING STATION

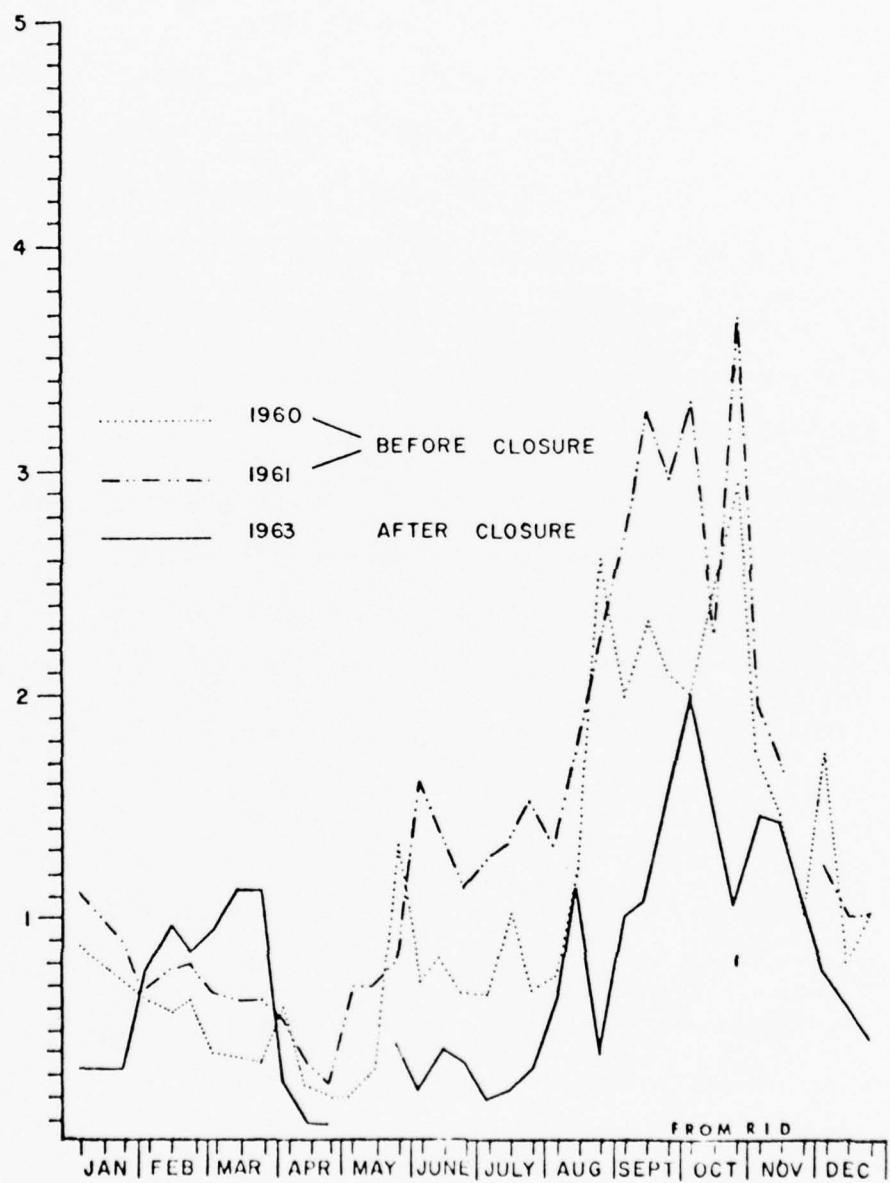


Figure 10. Maximum height hydrograph for Ping River at a station below the Phomiphol Dam. Graph shows water level fluctuations before and after closure of the dam. Note how the dam has evened-out flow.

problems experienced by shipping on the main stream. At the same time, this diverted water is channeled through the Suphan and the Noi distributary channels where regulators keep water levels sufficiently high for all year-round navigation. Therefore, at the same time that the impact of the Chao Phaya dam works to restrict the shipping season on the middle reaches of the Chao Phaya river, it acts to extend the shipping season on the parallel Noi and Suphan distributaries from a mode allowing high water movement only to a situation where all year shipping is possible. Figures 5 and 6 illustrate how water control regulators on the Suphan work to even out variations in water depth on the navigation channel.

Because the Chao Phaya dam is primarily a diversion barrage with a small reservoir, water backing up behind the dam does have the effect of facilitating navigation on the upper Chao Phaya river. Yet, the dam's capacity to store water is very small. For this reason, its ability to even out the wide seasonal fluctuations in river flow and to prevent downstream flooding is limited. In order to provide greater water storage and control facilities and to provide hydroelectric power as well, large multipurpose dams were designed for the Ping and the Nan rivers, the Phomiphol dam now operating on the Ping river and the Nan river dam presently under construction.

Both of these large dams have large reservoir capacity. Their impact will be to even the flow of water downstream on both a rainfall to rainfall basis as well as on a season to season basis. These dams will smooth out the water surface hydrographic curve by avoiding conditions that cause either extensive flooding or drought. In terms of

downstream navigation, the effect of these dams will be to improve dry season passage by making more water available to the main stream. The demands of the irrigation system, however, could claim the additional water these structures make available in the dry season. To date, there seems to have been no large increases in dry season water levels on the main Chao Phaya river below the dam although the Phomiphol Dam has managed to keep water levels from falling below certain minimum levels.<sup>29</sup> What remains to be seen is if the improvements in water control made possible by these dams are to be used to hold water for later diversion to the irrigation system and thus reduce rather than increase dry season navigation on the Chao Phaya river or if they are to be used to maintain downstream barge passability. Because navigation and irrigation will ultimately be in competition for this water resource, the long-range effect of these dams could possibly work against water transportation instead of in its favor. See Figure 10 for illustration of the Phomiphol dam's impact on flow in the Ping river.

#### Channel Depth

The depth of water in the channels of the Chao Phaya system varies in accordance with the highly seasonal precipitation regime. The greatest aberrations in channel depth occur in those portions of the system where water levels are not maintained at a specified depth by dams or regulators.

Within the area under examination, it is the mainstream Chao Phaya river which experiences the greatest seasonal extremes in discharge and water level. Wide fluctuation is especially pronounced below

the Chao Phaya dam. Here water levels not only react to seasonal fluctuations in precipitation and surface runoff but also to the fact that a good deal of water is diverted above the dam for irrigation.<sup>30</sup>

In the upper portions of the Chao Phaya, the reservoir of the Chao Phaya dam maintains water levels at sufficient depth for year-round navigation as far upstream as Phayuha Khiri.<sup>31</sup> Beyond this point upstream to the northern terminus of the river at Nakhon Sawan, there are areas that become shallow during the dry season. The most critical are located at Kok Pra and within the limits of the city of Nakhon Sawan. Despite these areas of low water, barge traffic is not stopped from using the upper Chao Phaya river but travel time is greatly increased from one day to as much as a week or more between Nakhon Sawan and Phayuha Khiri.

The hydrographs presented in Figures 3, 4, 7, 8 and 9 illustrate the great fluctuations in water depth experienced along a large segment of the middle Chao Phaya river. Although heavily traveled by loaded commercial barges in the wet season, dry season navigation on the middle region of this river is sharply curtailed.

The Suphan river with the Chao Ched canal and the Noi river are both all season routes that are used by long-haul vessels as alternatives to the middle Chao Phaya river. The Suphan and the Noi are diversion canals and are integral parts of the Greater Chao Phaya Irrigation Project. The waters of these canals also show the seasonal fluctuation in the water budget, but a series of regulation weirs and navigation locks placed along their course function to maintain levels above those that would otherwise be too shallow for barge navigation.<sup>32</sup>

When the Greater Chao Phaya Project was being installed in the 1950's, it had been assumed by the Irrigation Department that water levels on the Suphan and Noi rivers would never fall below two meters in depth.<sup>33</sup> Since then the figures have been revised downward. Presently there are some places along the Noi and Suphan routes where dry season water levels do reach one meter in depth.

Despite the fact that in certain places water levels on these channelized routes do drop to levels that threaten safe navigation at certain times of year, the Suphan river hydrograph presented in Figure 11 shows that, on the average, levels below 1.50 meters are reached only twice and for very brief periods of time in May and October. Most of the year, the average level is in excess of the two meter mark. Another hydrographic recording taken at the Pholthep regulator, a water control device located at the northern junction of the Suphan and the Chao Phaya rivers upstream of Chai Nat, effectively illustrates how water levels on the Suphan canal side of the regulator are manipulated to avoid the highs and the lows experienced on the Chao Phaya river side of the barrier. When looking at this hydrograph, Figure 5, it must be kept in mind that the waters of the Chao Phaya river at this point are kept from falling during the dry season by the Chao Phaya dam located a short distance downstream. Before this structure went into operation in 1957, water levels fluctuated a great deal more thus decreasing the Suphan's stability as well.

WATER SURFACE LEVEL SUPHAN RIVER  
THABOTE REGULATOR 1957-1964  
DOWNSTREAM SIDE

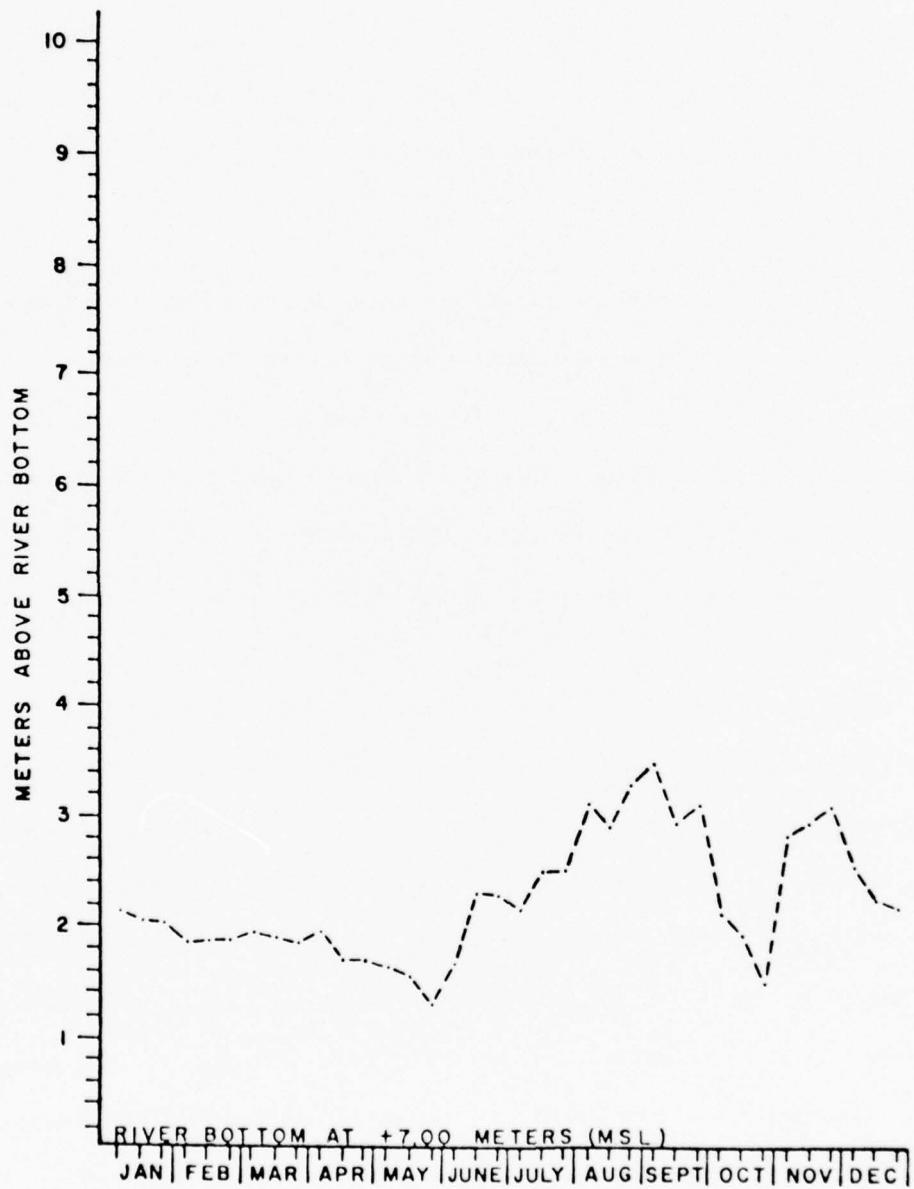


Figure 11. Maximum height hydrograph of average water surface level recorded on the 5th, 15th and 25th of every month on the Suphan River, 1957-1964.

Other Factors Reducing Water Transport's Efficiency

In addition to the problems inherent in low water levels, there are others which decrease the efficiency of water transportation. Those factors which are physical include sandbars, water currents and channel configuration. Other problems include navigation locks, traffic congestion and other obstructions.

Sandbars

Shallow conditions to the extent where barge passage is hampered are usually not a continuous phenomena except in the extreme northern headwaters of the river system. In the middle reaches of the Chao Phaya river intermittent shallowness usually assumes the form of sandbars in areas of reduced flow due to channel sinuosity or in areas where the waters of the river channel spread out to cover an extensive surface of the river bottom.

Within the middle Chao Phaya river it is dry season shallowness that introduces the major inefficiencies into long-haul water transportation. Loaded commercial vessels with drafts in excess of one meter are unable to use the middle Chao Phaya river from the Chao Phaya dam to Ayutthaya due to dry season shallowness caused in large part by sand deposits. On both the Noi and the Suphan routes, as already pointed out, depths are maintained through the use of regulators. To pass through the locks that move traffic around these regulators only increases travel time and travel cost and thus decreases water transportation's ability to compete with road and rail. Stated in its simplest terms, increasing channel depth in the main Chao Phaya river between the dam and Ayutthaya

would also increase the speed at which shipping could travel through the middle Chao Phaya region in the dry season. This, in turn, would greatly enhance the competitiveness of water transportation.

#### Water Currents

Water current can often present a problem for inland shipping. Each year there are incidents of boats running aground, striking other vessels, being smashed against bridge abutments by the current or damaged by large logs or other debris carried in the grip of powerful currents.

Dangerously swift currents are the result of two different forces. One is the river current that results from the abundant amounts of water seeking to exit to the sea during the rainy season. This current is a uni-directional phenomenon and is a major problem in the middle or the upper reaches of the system where channels are narrow and highly sinuous. The other type of current is tidal in origin and is felt more than 100 kilometers upstream from the Gulf of Thailand.

As already mentioned, many of the rivers and canals on the lower Central Plain have beds that are near or below mean sea level. As illustrated in Figure 12, this condition is found to exist on the Chao Phaya river as far inland as Ayutthaya, 136 kilometers from the Gulf of Thailand. On this waterway, variable tidal motion extends far upstream.<sup>34</sup> The magnitude and extent of the tidal impact varies seasonally in conjunction with the discharge rate of the Chao Phaya river. Something of an inverse relationship exists between seaward flowing river currents and inland flowing tidal thrust. When the tide is rising, it acts as a dam against the river current and slows its velocity. When the tide is ebbing, it reinforces the river current, in-

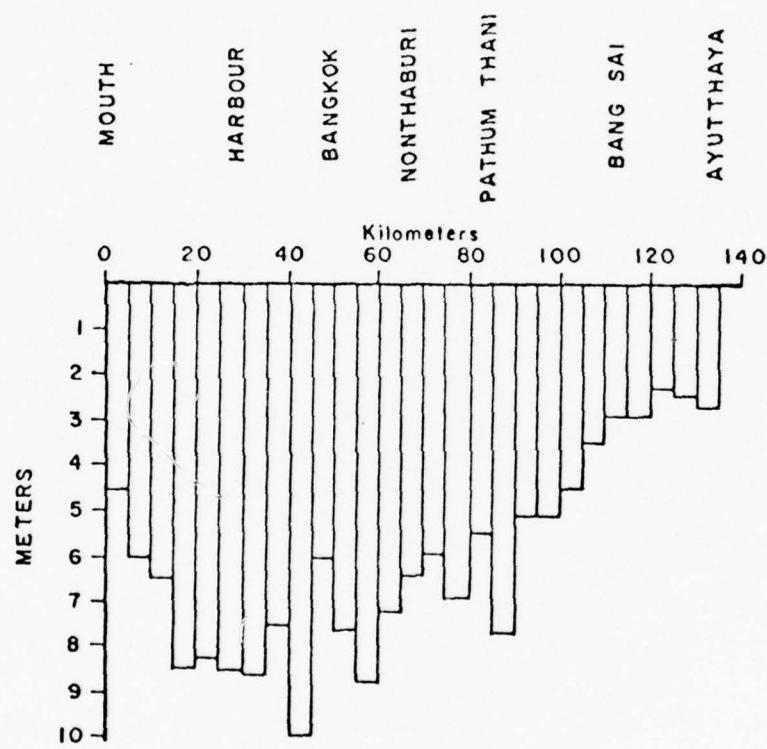


Figure 12. Chao Phaya River mean water depth below mean sea level. Taken from: Thailand, Port authority of Thailand, Marine Department, Marine Surveying Division, "Hydrographic and Hydrological Information, Bangkok Bar and Chao Phaya River, Thailand" Bangkok, September, 1966, p. 6. (Mimeographed.)

creasing its velocity. The effects of the tide are felt most acutely in the dry season when the reduced flow in the rivers results in decreased river currents. Within the estuary of the Chao Phaya, river discharge acts to impede the inland sweep of the tide during the rainy season when the river's flow is the greatest. At this time, the upper limits of the tide's influence are pushed seaward.<sup>35</sup>

Figure 13 displays the impact of the tides on the Chao Phaya river. It will be noted that the farthest upstream reach of tidal influence is 160 kilometers to Pamok, a town on the middle Chao Phaya river between Ayutthaya and Ang Thong. This occurs in the dry season.

Table 6 presents statistics on the variable rise and fall of water levels by season at various points within the lower Chao Phaya river estuary with respect to standard mean sea level.<sup>36</sup>

The currents that accompany the riverine and tidal flows have a significant impact on the ease of water transport. In the rivers and canals as well as the Chao Phaya itself, the tidal rise and fall of waters must be taken into consideration by barge operators. In all channels that experience tidal ebb and flow, current can present a navigational problem, the magnitude of its impact once again reflective of river discharge.

In the river part of the Estuary up to Bang Sai the character of the current varies between pure tidal in the dry season and almost riverain [riverine] when the river discharge reaches its maximum. The amplitude of the tidal velocities during the dry season gradually decreases from a mean value of 1.3 m./sec. at the river mouth to 1.2 m./sec. at Bangkok and 0.6 m./sec. at Bang Sai.

The discharge of the river weakens the flood and strengthens the ebb. At Bang Sai the maximum non-tidal discharge velocity was about 1.1 m./sec. In the tidal reaches the ebb currents can attain velocities of little less than 2.5 m./sec.<sup>37</sup>

Strong riverine currents can, however, add to the efficiency of cargo transfer by increasing downstream vessel speed. This is es-

pecially true during the period of peak flow when the rivers and canals of the Chao Phaya system are at their deepest and broadest stage while many potential hazards such as sandbars, built up during the dry season, are either swept away by scour or submerged well below the water's surface. Where channels are narrow and of sinuous configuration or where surface or subsurface obstructions, such as bridge abutments, are found, the rainy season's strong riverine currents do present a hazard to navigation. It is under these conditions just outlined that the power of one's towboat and the skill of its operator become quite important along with the length and composition of the barge string to which one's barge is attached.

During periods of less than peak flow, currents are less strong and the damming effect of tidal flow may even have a beneficial effect in that it tends to increase channel depth by backing up water. In general, however, as water levels drop, the condition of the navigation channel also deteriorates to the point that, at low water, constrictions and obstructions become the major problem. At the same time currents can still maintain very high velocities along certain stretches of a channel as is the case on the outside edge of river meanders or where channel width is constricted by sandbars. These localized problem areas present towboat and barge operators with the dual hazard of swift currents and tight bends which singularly or in combination work to compound the dangers of safe vessel passage.<sup>38</sup> It is under such conditions that dry season currents can present a problem to shipping while providing only minimum thrust to downstream vessel movement.

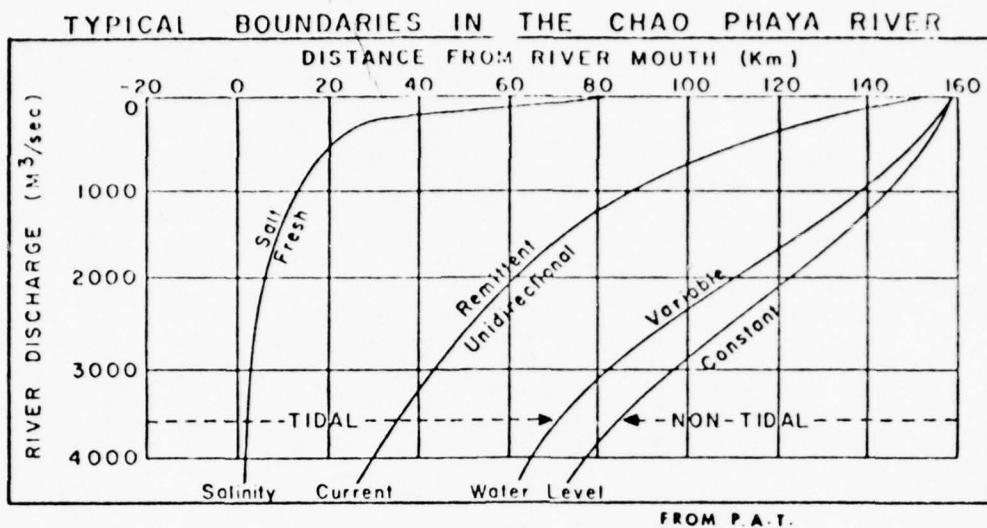


Figure 13

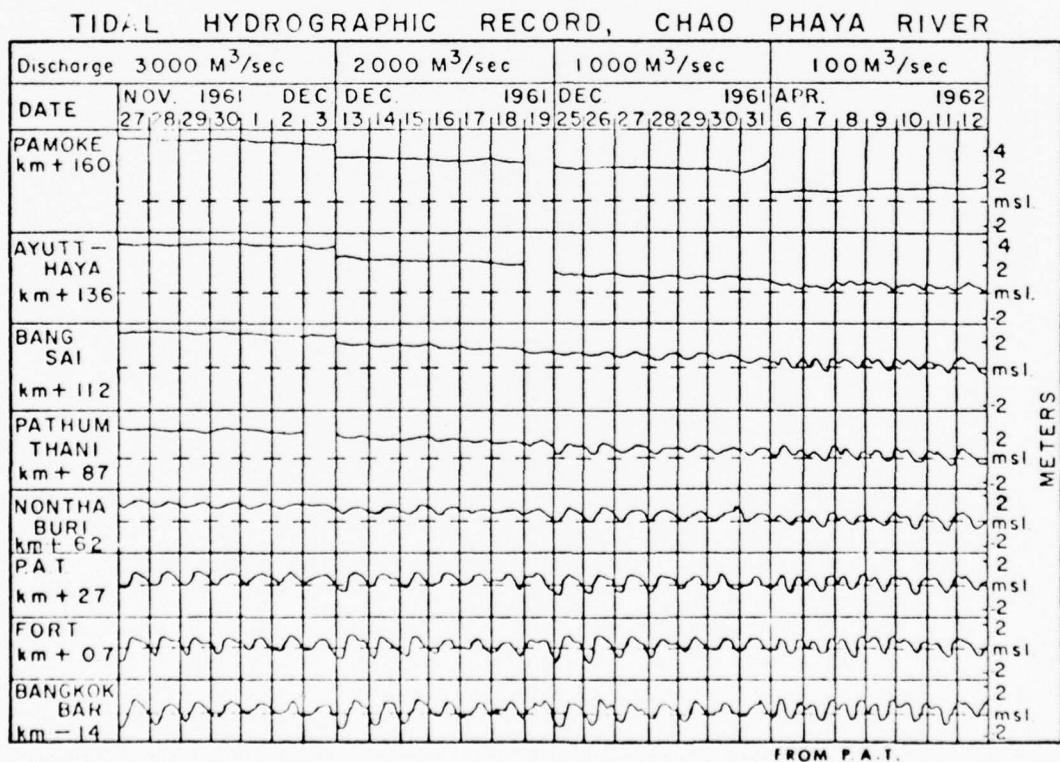


Figure 14. Hydrographic record showing tidal impact by season at different locations on the Chao Phaya River.

TABLE 6  
TIDAL DATA FOR THE CHAO PHAYA RIVER -- METERS  $\pm$  MEAN SEA LEVEL

	Kilometers from Mouth	LLW	MLLW	MLW	MTL	MHW	MHHW	HHW
Bangkok Bar	-14	-2.42	-1.31	-0.76	+0.05	+0.91	+1.14	+2.01
Fort Pra Chyla	+ 1	-1.79	-1.07	-0.63	+0.09	+0.09	+1.12	+1.89
Paknam	+ 7	-1.76	-1.02	-0.58	+0.10	+0.89	+1.10	+1.87
Phra Pradaeng	+18	-1.72	-0.90	-0.48	+0.19	+0.94	+1.13	+1.90
Port Authority	+28	-1.63	-0.85	-0.45	+0.21	+0.93	+1.11	+1.86
Hydro. Dept.	+49	-1.62	-0.61	-0.25	+0.33	+0.92	+1.05	+2.42
Nontha Buri	+62	-1.59			+0.42			
Pathum Thani	+85	-1.57			+0.63			+2.52
Bang Sai	+110	-1.33			+0.26	+0.97	+1.13	+3.99
Ayutthaya	+136	-0.30			+1.33	+1.63	+1.78	+4.98
Pa Moke	+160	+0.63			+2.86	+2.89	+2.92	+5.58

LLW: Lowest Low Water

MLLW: Mean Lower Low Water

MLW: Mean Low Water

MTL: Mean Tide Level

MHW: Mean High Water

MHH: Mean Higher High Water

HHW: Highest Higher Water

Source: Port Authority of Thailand, Marine Department, Marine Surveying Division, Hydrological Information Bangkok Bar and Chao Phaya River, Bangkok, 1966.

### Channel Configuration

The configuration of a channel, i.e., width and sinuosity, is an important factor governing the speed and ease with which a string of barges can negotiate a waterway. If a channel is highly sinuous not only does its actual distance increase with each change in direction, but every turn requires added concentration and effort on the part of the towboat operator and the barge men manipulating the craft following behind. Sinuosity may be the main factor in determining the number of barges pulled by each towboat. It substantially reduces the speed at which barge strings can travel.

If, in addition to being sinuous, a channel is also narrow, as is the case on much of the Noi and the Suphan rivers, or if approaching traffic is heavy, the difficulty of guiding a string of barges through a navigation channel is compounded still further.

The waterways of the Chao Phaya system run the entire range of extremes from being broad and relatively straight navigation channels to being narrow river courses displaying great sinuosity. Of all the navigation routes in the Chao Phaya system, the lower Chao Phaya river below Bang Sai comes closest to having a configuration ideal for easy navigation. At all times of the year, its waters are deep and broad.<sup>39</sup> Although the river is not free of some meandering, these undulations are both sweeping and broad. On the lower Chao Phaya river only near Pak Kret does channel meandering pose a problem for large barges.

At the opposite extreme, the rivers of the upper tributary region possess a high degree of sinuosity while being both narrow and

of shallow depth much of the year. These waterways, the Ping, Wang, Yom and Nan, all display great seasonal difference in flow. Only during the high water stage are they navigable by loaded commercial barge and only with some difficulty except on the more accommodating Nan. All these northern rivers display a sinuosity and abundance of sandbars and sand banks that make barge movement difficult or impossible during most of the year. Barge operators with vessels of all sizes consider the Nan and the Yom to be problem streams. The Ping rivers is so difficult to navigate, especially since the installation of the dam at Yanghee, that it wasn't even considered as a navigable link with the system by those filling out Project 30 questionnaires.<sup>40</sup>

Intermediate between the two extremes just discussed are the waterways of the middle and the upper Chao Phaya region. During the high water period, the middle Chao Phaya river is a broad, easily travelled waterway displaying wide bends and a gently undulating configuration. During the dry season, low water conditions cause the waterway to shrink between its high banks and become a shallow waterway whose hard, sharp bands combine with sandbars and shallows to make navigation a hazardous undertaking.

Although both the Suphan and the Noi rivers have more constant water levels, configuration is a problem on both routes. On the Noi, configuration is a problem for vessels of all sizes and, during the time of lowest water, shallow conditions make this route unattractive to loaded large barges (capacity over 900 sacks of rice or 90 tons) and medium size barges (500 to 900 sacks of rice or 50 to 90 tons capacity).<sup>41</sup> The Supahn's configuration is a problem also but not to the same degree as that of the Noi. Thus, the Suphan river

provides the most preferred dry season route for loaded barges of any size.<sup>42</sup>

Table 7 presents a comparison between direct line distance and distance as measured around each bend in the Chao Phaya, Noi and Suphan rivers. An analysis of the measurements shows that the Suphan river has the most kilometers added due to sinuosity. The Noi is next in order of length added followed by the Chao Phaya. Although the statistics give us an idea of length added by the twisting and turning of each river, they do not indicate that the longer river is the more difficult to navigate because of this sinuosity. In fact, according to responses made on the general barge questionnaire, barge operators found the Noi river's configuration a greater problem to cope with than that of the Suphan river, due to the tightness of many of its bends.

In summary, this report discusses those physical factors which increase both travel time and costs to commercial barge traffic over the three major routes of the Chao Phaya system. While individual barge operators can exercise a range of options which minimize some of these constraints, the net result of most of these responses is reduced efficiency to the industry as a whole. The most wide-sweeping and effective solution to the navigational problems would be a deeper waterway that does not have swift currents or a high degree of sinuosity. Such a waterway is now available in the main Chao Phaya only during the high water period. If it were possible to extend that period, many of the constraints presently limiting the efficiency of waterway shipping would be eased. Translated into savings in time and money, all year use of the Chao Phaya should enhance the competitive position of water transportation.

TABLE 7

A COMPARISON OF DISTANCES MEASURED FOLLOWING WATER COURSES AND DISTANCES  
MEASURED FOLLOWING WATER COURSE TREND BUT CUTTING ACROSS BENDS  
AND MEANDERS, MIDDLE REGION OF THE CHAO PHAYA RIVER SYSTEM  
(IN KILOMETERS)

	Water Course	Direct Distance	Difference
<b>Chao Phaya River</b>			
Junction with Suphan River to In Buri	44.00 <sup>ab</sup>	35.50 <sup>a</sup>	8.50
In Buri to Ang Thong	60.00 <sup>b</sup>	52.00 <sup>a</sup>	8.00
Ang Thong to Bang Sai a. via Ayutthaya Ring b. via Klong Bang Ban	65.00 <sup>a</sup> 60.00 <sup>b</sup>	55.00 <sup>a</sup> 53.00 <sup>a</sup>	10.00 7.00
Routes:	a. 26.50 km. added b. 23.50 km. added	by sinuosity	
<b>Noi River</b>			
Junction with Chao Phaya to Bang Rachan	49.00 <sup>a</sup>	37.50 <sup>a</sup>	11.50
Bang Rachan to Wiset Chai Chan	53.00 <sup>a</sup>	40.00 <sup>a</sup>	13.00
Wiset Chai Chan to Sena	36.00 <sup>a</sup>	31.00 <sup>a</sup>	5.00
		29.00 km. added	
<b>Suphan River</b>			
Junction with Chao Phaya to Tabot Lock	30.00 <sup>ab</sup>	21.50 <sup>a</sup>	9.00
Tabot Lock to Cholmak Lock	50.00 <sup>b</sup>	36.00 <sup>a</sup>	14.00
Cholmak Lock to Junction with Chao Ched Canal	60.00 <sup>b</sup>	49.00 <sup>a</sup>	11.00
		34.00 km. added	
<b>Chao Ched Canal (Suphan Route)</b>			
From Suphan river to Bang Sai on Chao Phaya	61.00 <sup>a</sup>	51.50 <sup>a</sup>	10.00
		10.00 km. added	

<sup>a</sup>Army Map Service, 1:50,000, compiled 1960.

<sup>b</sup>RID Map of Central Plain of Thailand, 1:400,000, 1957.

## FOOTNOTES

<sup>1</sup> Robert L. Pendleton, Thailand: Aspects of Landscape and Life. An American Geographical Society Handbook (New York: Duell, Sloan and Pearce, 1962), p. 113.

<sup>2</sup> Ibid., p. 118.

<sup>3</sup> Howard F. Haworth, Ponpan Na Chiangmai, and Charoen Phiancharoen, Ground Water Resource Development of North-Eastern Thailand, Ground Water Bulletin No. 2, Prepared in Cooperation with the United States Overseas Mission to Thailand (Bangkok: Ministry of National Development, Department of Mineral Resources, Ground Water Division, 1966), p. 13.

<sup>4</sup> These statistics are derived from Table 1.

<sup>5</sup> Much less critical than the fluctuations in the precipitation regime are the annual differences in atmospheric temperatures throughout Thailand. In keeping with the tropical nature of this climate region, the magnitude of annual temperature change is minimal while at the same time of a predictable nature. Based on temperature data presented in this chapter, the average temperature variation between Bangkok's coolest month, December, and its warmest, April, is only 8.64 degrees Fahrenheit. From Nakhon Sawan, located at the top of the Bangkok Plain, the annual average monthly disparity is only 11.8 degrees. In Chiang Mai, located in the northern hills, the difference amounts to 12.60 degrees.

<sup>6</sup> Pendleton, Thailand, p. 113.

<sup>7</sup> E. H. G. Dobby, Southeast Asia (London: University of London Press, 1950), p. 38.

<sup>8</sup> Pendleton, Thailand, p. 113.

<sup>9</sup> Dobby, Southeast Asia, p. 38.

<sup>10</sup> Pendleton, Thailand, p. 115.

<sup>11</sup> Lawrence Sternstein, The Rainfall of Thailand, ed. by Don C. Bennett (Bloomington, Indiana: Indiana University Foundation Research Division, n.d.), p. 70.

<sup>12</sup> Pendleton, Thailand, p. 115.

<sup>13</sup> Luna B. Leopold, M. Gordon Wolman, and John P. Miller, Fluvial Processes in Geomorphology (San Francisco: W. H. Freeman and Company, 1964), p. 509.

<sup>14</sup> Charles H. Pierce, "Methods of Stream Gaging," in Hydrology, ed. by Oscar E. Meinzer, Dover Publications, Inc. (New York: McGraw-Hill Book Company, Inc., 1942), p. 486.

<sup>15</sup> Arthur N. Strahler, Physical Geography (2nd ed.; New York: John Wiley & Sons, Inc., 1960), p. 336.

<sup>16</sup> Ibid., p. 335.

<sup>17</sup> Ibid.

<sup>18</sup> Ibid., p. 336.

<sup>19</sup> Pierce, Hydrology, p. 486.

<sup>20</sup> Ibid., p. 491.

<sup>21</sup> "Rapport De La Mission Effectuée En Thailand Sous Les Auspices De La Commission Economique Pour L'Asie Et L'Extreme Orient" (unpublished report of the Mission Française De Cooperation Technique Pour L'Etude Des Possibilités D'Application De Nouvelles Méthodes D'Amenagement Des Riviers Par Utilisation Des Courants Secondaires Crées Par Panneaux De Fond Ou De Surface, Thailand August, 1963), p. 16.

<sup>22</sup> Velocity is not constant in all parts of the channel owing to its sinuosity during the dry season. Under dry season conditions, some areas, especially on the outside of curves, experience high velocity while other areas, especially in the shallower inside of curves, carry water of reduced velocity.

<sup>23</sup> The Greater Chao Phaya Project (Bangkok: Ministry of Agriculture, Royal Irrigation Department, February 7, 1957), p. 17.

<sup>24</sup> Ibid.

<sup>25</sup> Many years of indiscriminant lumbering operations throughout the upland margins of the Chao Phaya watershed have downgraded the woodland into scrub forests. In many places the soil has become severely laterized and eroded. These conditions have had a detrimental effect on the watershed by increasing runoff and siltation.

<sup>26</sup> The Greater Chao Phaya Project, p. 17.

<sup>27</sup> Ibid.

<sup>28</sup> Ibid.

<sup>29</sup> According to French engineers assisting in river training on the middle Chao Phaya river, the Phomiphol dam will be able to maintain water discharge levels at a minimum of 100 m<sup>3</sup>/sec.

<sup>30</sup> The Greater Chao Phaya Project, p. 23.

<sup>31</sup> M. Remillieux, "Report on the Mission Carried Out in Thailand in December 1966, Under the Auspices of the Economic Commission for Asia and the Far East" (unpublished report of the French Technical Cooperation for the Improvement of Water Transport, Centre De Recherches Et D'Essais De Chatou, Department Laboratorie National D'Hydraulique, Thailand, March, 1967), p. 17.

<sup>32</sup> The Greater Chao Phaya Project, p. 23.

<sup>33</sup> Ibid.

<sup>34</sup> Hydrographic and Hydrologic Information, Bangkok Bar and Chao Phraya River, Thailand (unpublished report by Port Authority of Thailand, Marine Department, Marine Surveying Division, Bangkok, September, 1966), p. 8.

<sup>35</sup> Ibid.

<sup>36</sup> This table was taken from Hydrographic and Hydrological Information, Bangkok Bar and Chao Phraya River, Thailand. In regards to this table, the source makes no mention of river discharge or season of the year. However, judging from the impact that high tidal stages have on the Phamok station, the writer assumes that this data was collected sometime during the dry season.

<sup>37</sup> Ibid., p. 11.

<sup>38</sup> Leopold, Wolman, and Miller, Fluvial Processes, p. 299.

<sup>39</sup> The width of the Chao Phaya river below Bang Sai varies between 400 and 500 meters. Within the city limits of Bangkok it is 180 meters wide. (Based on the U.S. Army Map service 1:50,000 scale map of Thailand compiled in 1960 and Hydrographic and Hydrologic Information, Bangkok Bar and Chao Phraya River, Thailand), p. 1.

<sup>40</sup> The Phomiphol dam is a multipurpose dam located on the Ping river below its confluence with the Wang river and above the city of Tak. The dam was completed in 1966 and has curtailed barge operation to an even higher degree on the Ping river.

<sup>41</sup> Project 30 divided barges into four categories according to cargo capacity. Classification was as follows:

Category	Symbol	Capacity
Very Small Barge	○ <sup>b</sup>	Under 30 tons or 300 sacks rice
Small Barge	○	30 to 50 tons 300 to 500 sacks rice
Medium Barge	△	50 to 90 tons 500 to 900 sacks rice
Large Barge	□	Over 90 tons More than 900 sacks rice

<sup>42</sup> This statement is based on responses given to the general barge questionnaire administered by Project 30 workers.

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#### ABSTRACT

This report discusses the physical constraints on navigation in Thailand which make it difficult for the commercial barge industry to compete for cargo with road and rail carriers on the Central Plain. The impact of such factors as wide seasonal variation in water flow, channel depths and configuration and the presence of other physical constraints such as sandbars or currents result in an increase of both costs and travel time for waterway shipping. The degree to which these constraints reduce the potential level of barge transport efficiency is described for the three major routes of the middle Chao Phaya system, the Noi, the Suphan and the Chao Phaya.

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